



ECOSTRESS end-to-end radiometric pre-flight calibration and validation

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SPIE 2018, San Diego, California

Paper 10764-6 of Session 1

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Time: 9:40 AM - 10:00 AM

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Outline

- **Brief background of the effort**
- **Basic science description**
- **ECOSTRESS sensor description**
- **Measurement requirements**
- **Tests performed**
- **Concluding remarks**

NASA's new Earth-observing experiment, ECOSTRESS, lifted off towards the International Space Station. Dragon lifted off on a Falcon 9 rocket from Space Launch Complex 40 at Cape Canaveral Air Force Station in Florida

Credit: NASA



HyspIRI Background

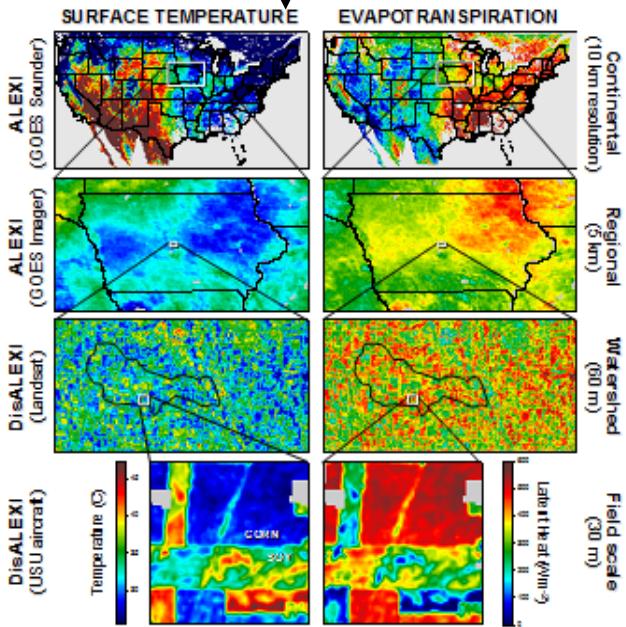
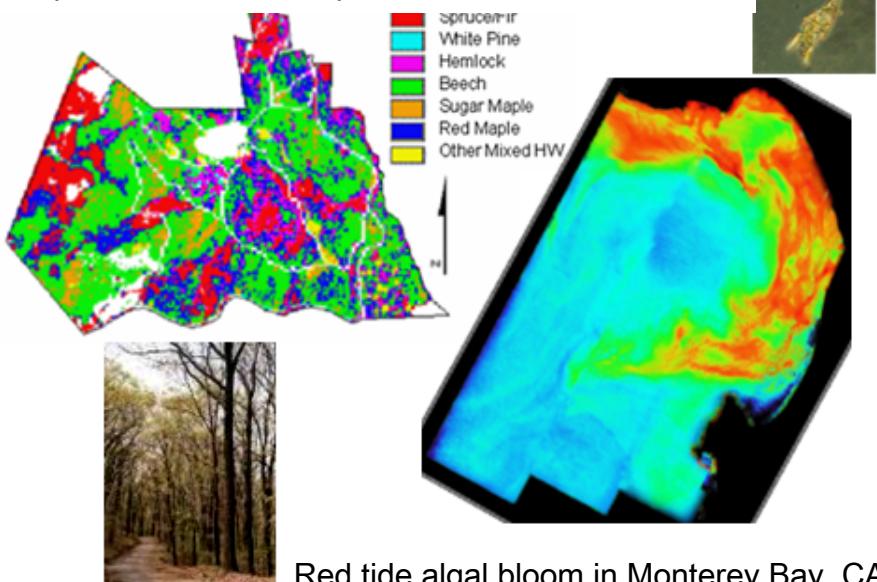
Visible ShortWave InfraRed (VSWIR) Imaging Spectrometer
+
Multispectral Thermal InfraRed (TIR) Scanner

VSWIR: Plant Physiology and Function Types (PPFT)



Multispectral TIR Scanner

Map of dominant tree species, Bartlett Forest, NH



HyspIRI Background



Science Questions:

TQ1. Volcanoes/Earthquakes (MA,FF)

– How can we help predict and mitigate earthquake and volcanic hazards through detection of transient thermal phenomena?

• TQ2. Wildfires (LG,DR)

– What is the impact of global biomass burning on the terrestrial biosphere and atmosphere, and how is this impact changing over time?

• TQ3. Water Use and Availability, (MA,RA)

– How is consumptive use of global freshwater supplies responding to changes in climate and demand, and what are the implications for sustainable management of water resources?

• TQ4. Urbanization/Human Health, (DQ,GG)

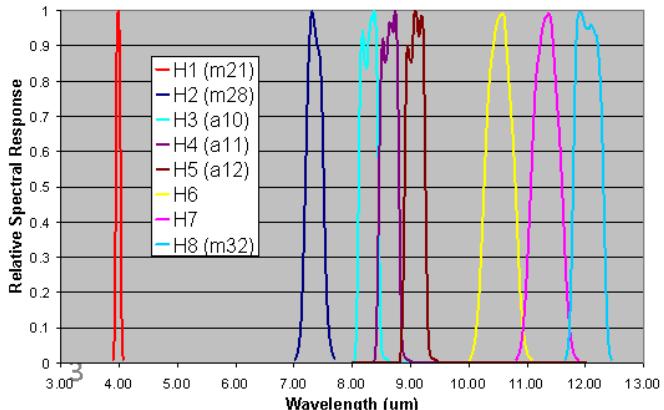
– How does urbanization affect the local, regional and global environment? Can we characterize this effect to help mitigate its impact on human health and welfare?

• TQ5. Earth surface composition and change, (AP,JC)

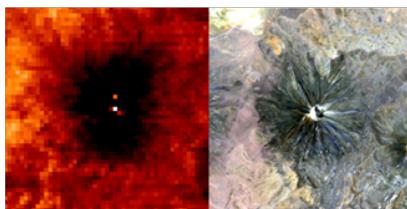
– What is the composition and temperature of the exposed surface of the Earth? How do these factors change over time and affect land use and habitability?

Measurement:

- 7 bands between 7.5-12 μm and 1 band at 4 μm
- 60 m resolution, 5 days revisit
- Global land and shallow water



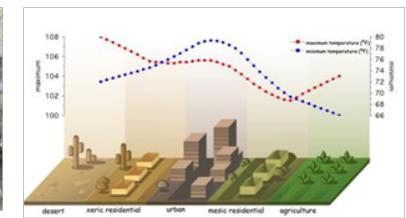
Andean volcano heats up



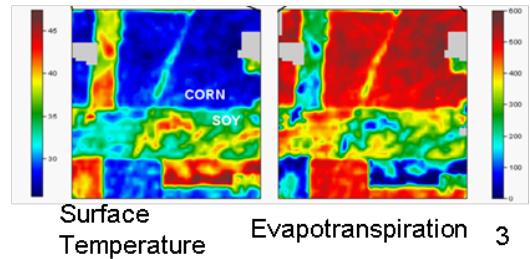
Volcanoes



Urbanization



Water Use and Availability

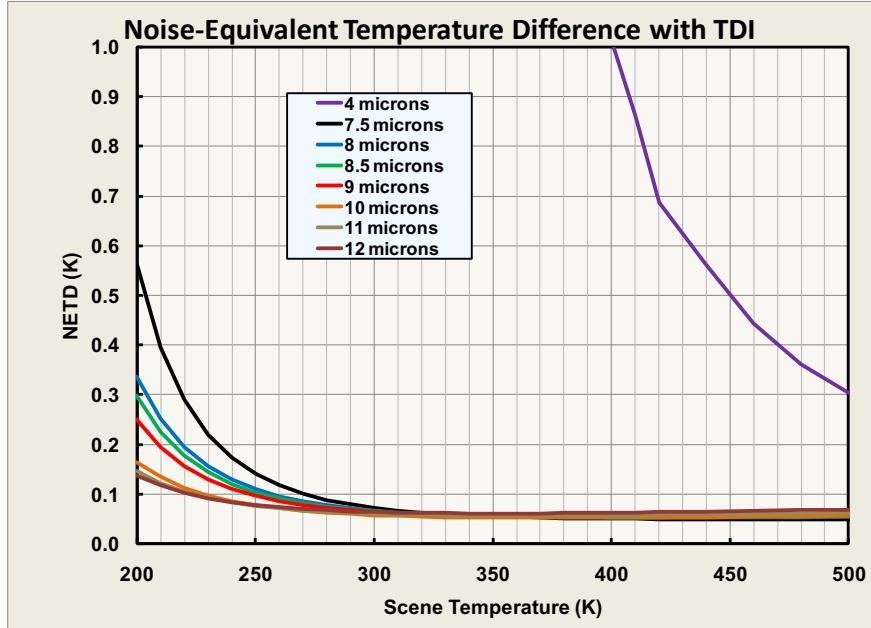




HypIRI Measurement Requirements

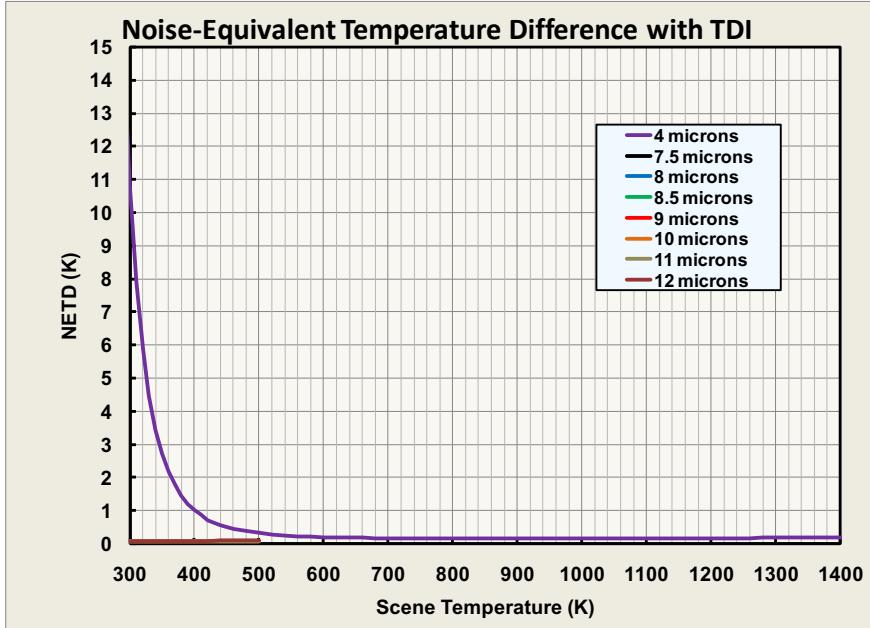
PARAMETER	BASELINE	SCIENCE REQUIREMENT
Ground Resolution (m)	60	<100
Revisit (days)	5	<6
Noise equivalent delta temperature (K)	0.2	<0.3
Absolute accuracy (K)	0.5	<1
Saturation – low temperature bands (K)	500	>400
Saturation – high temperature band (K)	1200	>1100
Overpass time (hh:mm)	10:30am	10-3pm
Nighttime imaging	Yes	Required
Number of Bands (spectral range: 3 – 12 μm)	8	≥ 8
Coverage	Land and coastal regions	Land and coastal regions
Data latency	2 days	< 1 week

HypIRI-TIR Radiometric Performance



Expected HypIRI-TIR Sensitivity Metric expressed as Noise Equivalent Delta Temperature (NEDT)

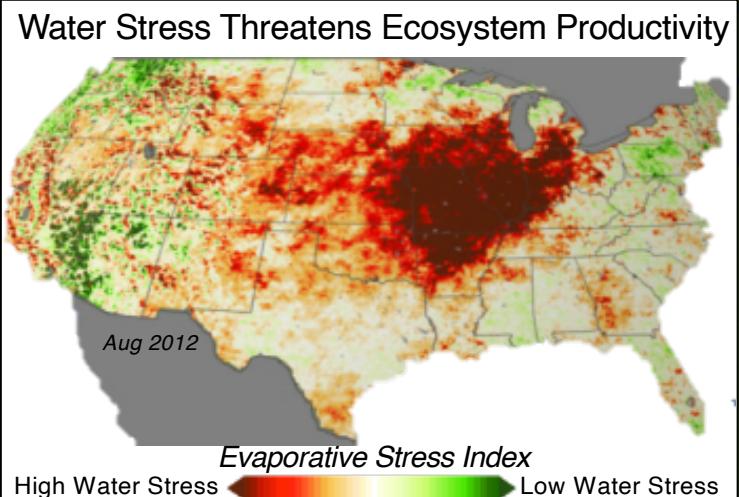
- Predicted sensitivity better than 0.2 K @ 300 K requirement.
- Good sensitivity in overlap region between channel 1 and channels 2-8.
- Expected saturation temperature of 1100K based on HypIRI: Hot Target Saturation Subgroup (HTSS)



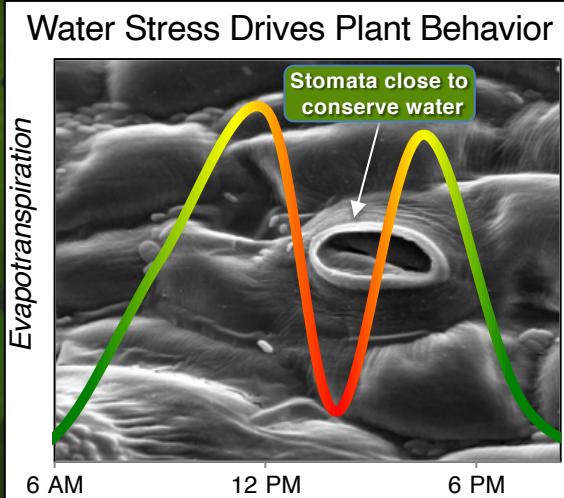
Expected HypIRI-TIR Sensitivity Metric expressed as Noise Equivalent Delta Temperature (NEDT)

ECOSTRESS Science Overview

ECOSTRESS will provide critical insight into **plant-water dynamics** and how **ecosystems change with climate** via **high spatiotemporal** resolution thermal infrared radiometer measurements of evapotranspiration (ET) from the International Space Station (ISS).



Water stress is quantified by the Evaporative Stress Index, which relies on evapotranspiration measurements.

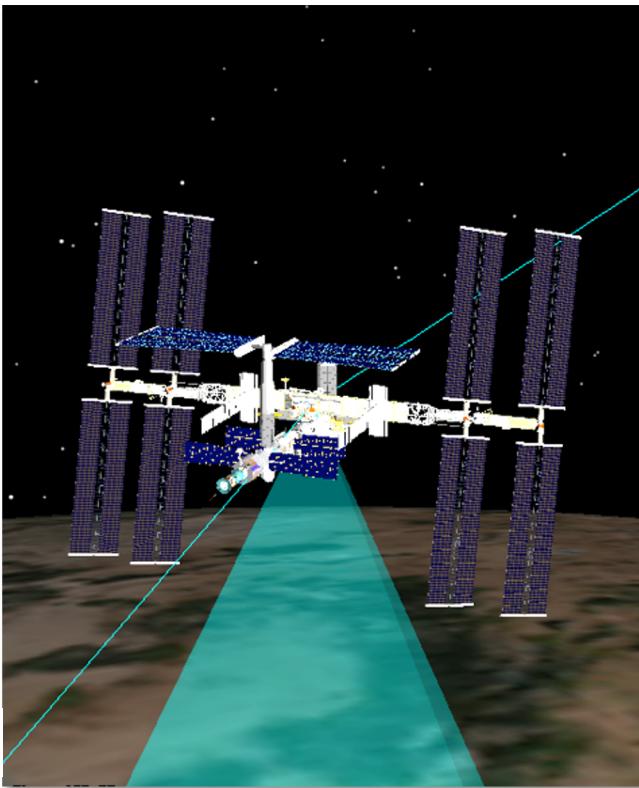
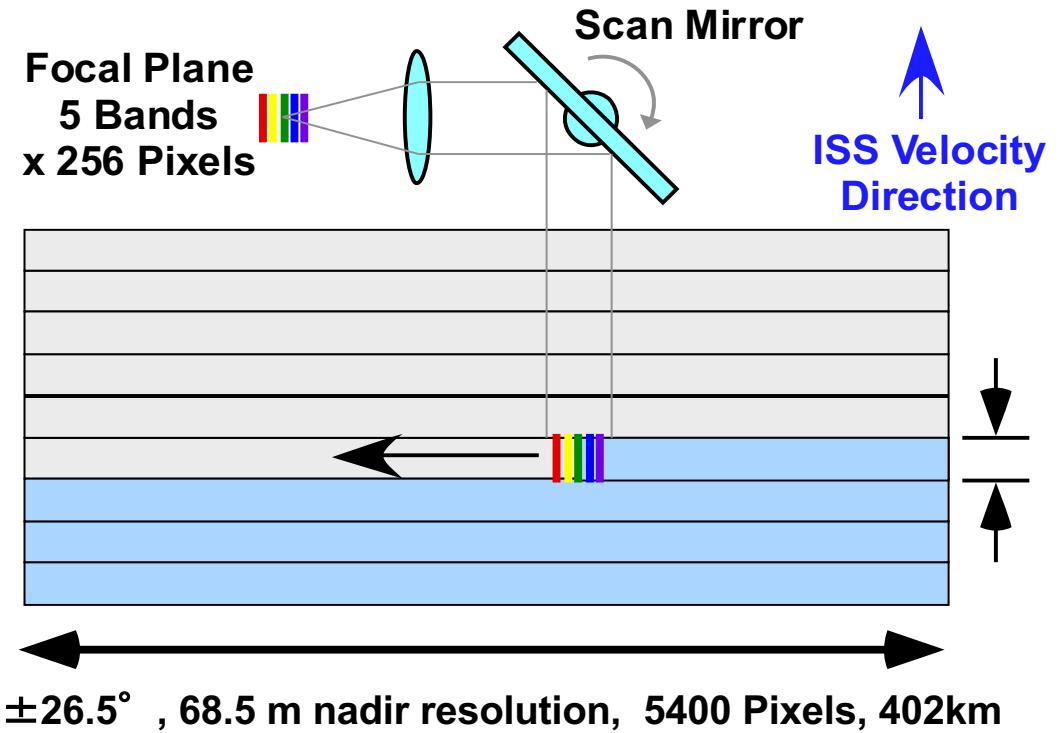


When stomata close, CO₂ uptake and evapotranspiration are halted and plants risk starvation, overheating and death.

Science Objectives

- Identify critical thresholds of water use and water stress in key climate-sensitive biomes
- Detect the timing, location, and predictive factors leading to plant water uptake decline and/or cessation over the diurnal cycle
- Measure agricultural water consumptive use over the contiguous United States (CONUS) at spatiotemporal scales applicable to improve drought estimation accuracy

Instrument Implementation

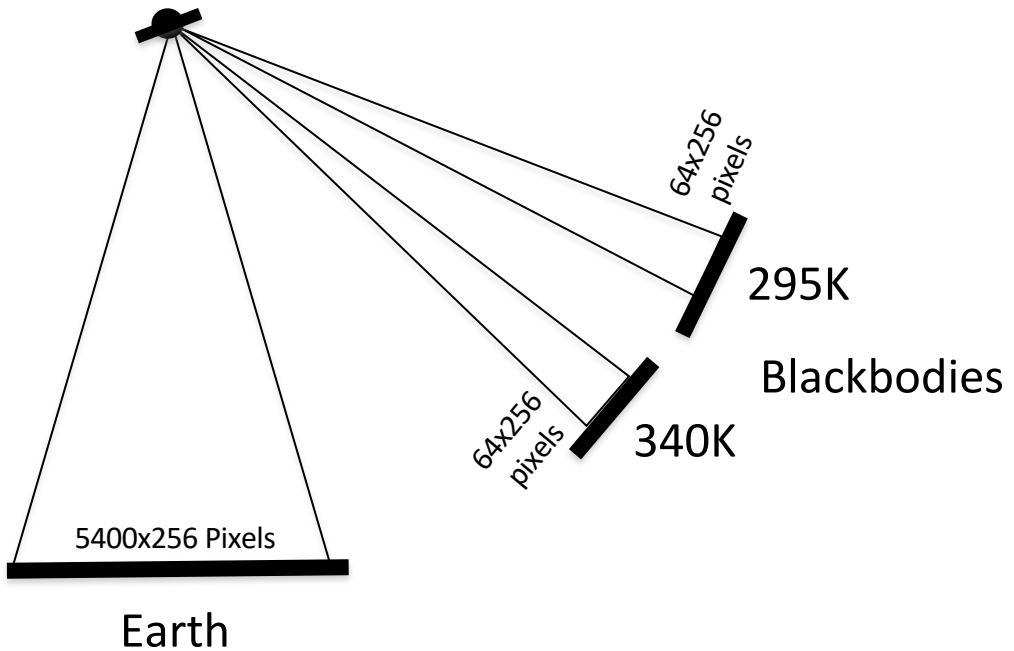


- 402 km swath width at 400 km altitude (*Requirement is ≥ 360 km*)
- 38.5 x 68.5 m Pixel Footprint at Nadir (*Requirement is ≤ 100 m*)
- Scan Mirror rotates to enable overlap between successive scans
- Pixel Dwell Time 32 microseconds

Onboard Calibration

One Band / Single Scan Simplification

Scan Mirror



- Earth = 5400x256 pixels
- Cold Blackbody = 64x256 pixels
- Hot Blackbody = 64x256 pixels
- Total one band / single scan = 5528x256 pixels
- Earth data product assumes 44 of these scans (with 256 pixels along track). So this creates a 5400 x 11264 pixel NADIR image.
- The 128x11264 pixels of BB calibration are separated from the Earth image but assembled, and downloaded as an “image”.
- On the ground each of the two BB sets are divided into their corresponding filters and combined/median/averaged to 1x256 pixel calibration files.



ECOSTRESS Sensor Calibration

Pre-flight testing and calibration:

- Temporal Precision:
 - 2-point radiometric calibration using high emissivity blackbody and 25C scene blackbody measurement.
- Absolute temperature accuracy and linearity at sensor:
 - 2-point radiometric calibration using high emissivity blackbody stepped in 5C increments between 5C and 65C.
- Along-track and cross-track Modulation Transfer Function (MTF):
 - Line spread function in perpendicular orientations.
- Stray light (measure out-of-field rejection and in-field performance):
 - Laser sphere output with tunable thermal IR laser stimulus
 - Laser point output with tunable thermal IR laser stimulus
- Radiance versus scan angle (RVS) for both sides of the mirror:
 - 2-point radiometric calibration using high emissivity blackbodies (320K and <300K) and 25C scene blackbody measurements positioned in 5° increments over the total 53° scan width.
- Spectral response function (SRF):
 - Monochromator scanned through the applicable wave space used in conjunction with target projector.
- Full field geometric distortion mapping:
 - Centroid an array of grid point sources using target projector

On-orbit Calibration:

- Precision and Absolute temperature accuracy at sensor:
 - 2-point radiometric calibration using high emissivity blackbodies (320K and <300K) with retro FPA view.

On-orbit Validation:

- Precision and Absolute temperature accuracy:
 - 2-point radiometric calibration using high emissivity blackbodies (320K and <300K) combined with known ground validation targets.

Digital Number to Radiance Value

$$R_\lambda = a + bD_\lambda$$

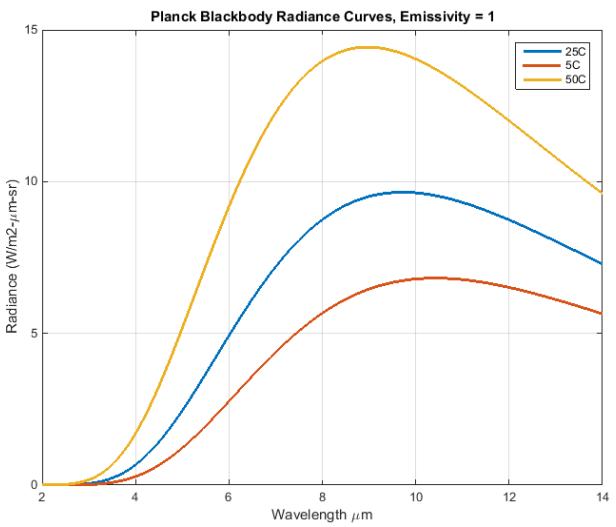
$$a = \frac{R_h D_c - R_c D_h}{D_c - D_h} \quad b = \frac{R_c - R_h}{D_c - D_h}$$

$$R_c = P(\lambda, T_c)$$

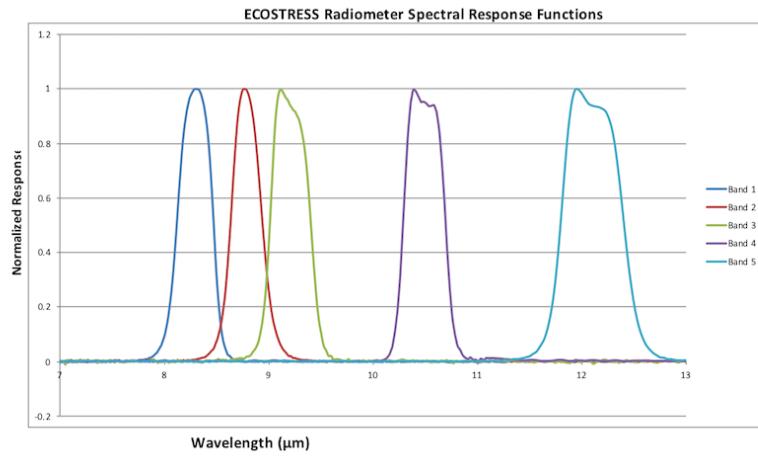
$R_h = P(\lambda, T_h)$

Preflight radiance linked to backside (bulk) temperature of the blackbody

Basic Two Point Calibration is Satisfactory



Planck function model



Normalized spectral response functions (SRF)

Laboratory Testing

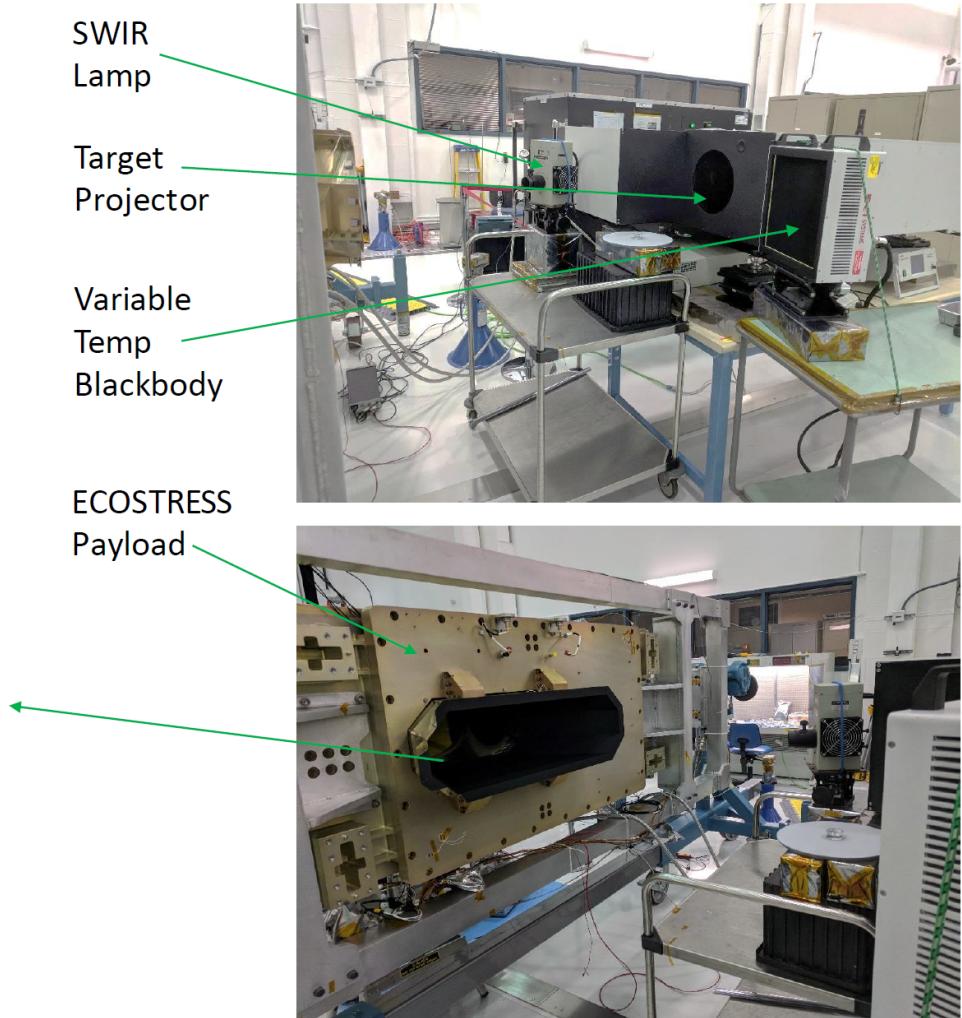
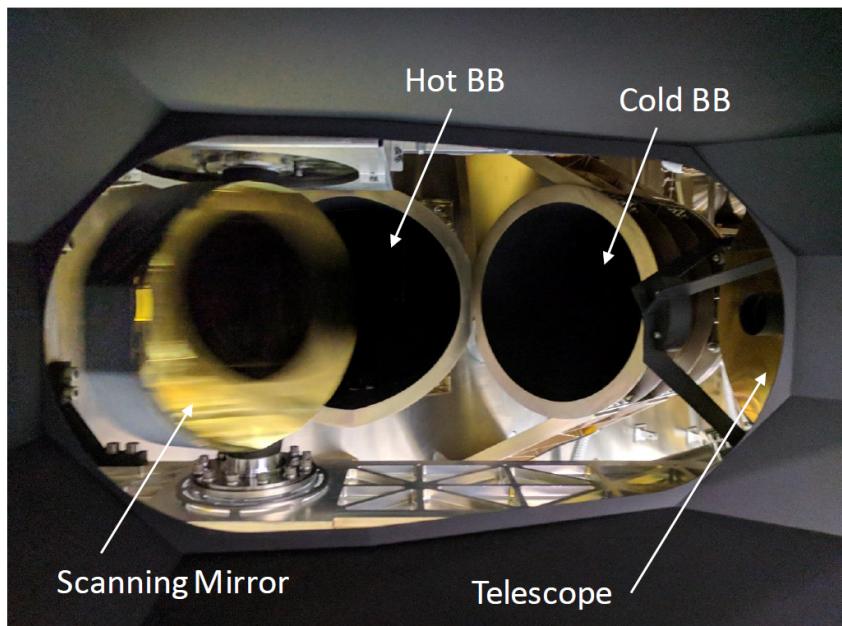


12/15/2017

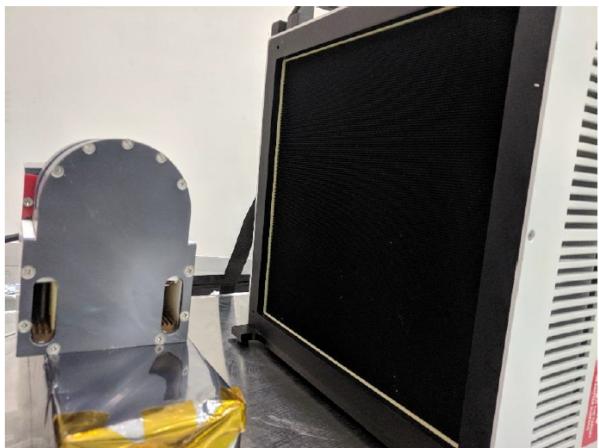
ECOSTRESS Pre-Vibe / Acoustic Dataset

Flight-like dataset saved through DPU-IO and SDS

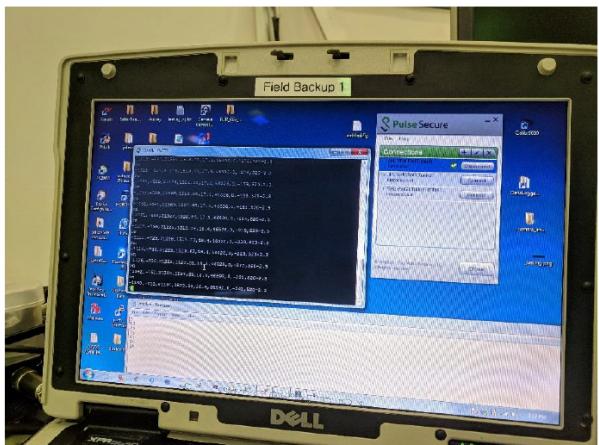
Option 1: Baseline operation, FPA at 65K,
Ambient laboratory environment (306-Hbay)



Thermal Measurement Traceability



NIST traceable transfer radiometer



Recorded output

11:00AM 2018-03-05 Transfer Radiometer 520

Environment: 20C T / 40% RH

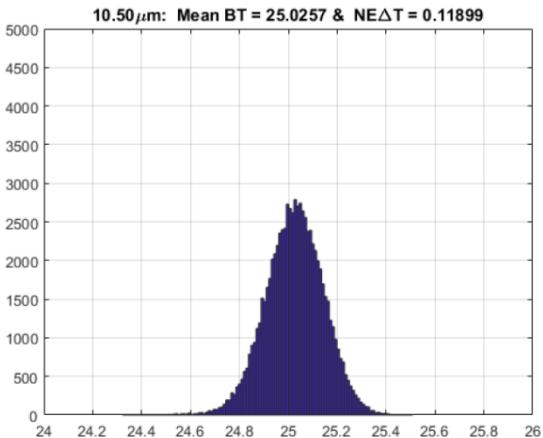
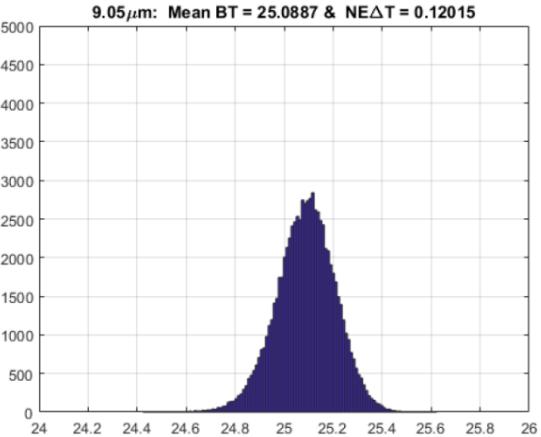
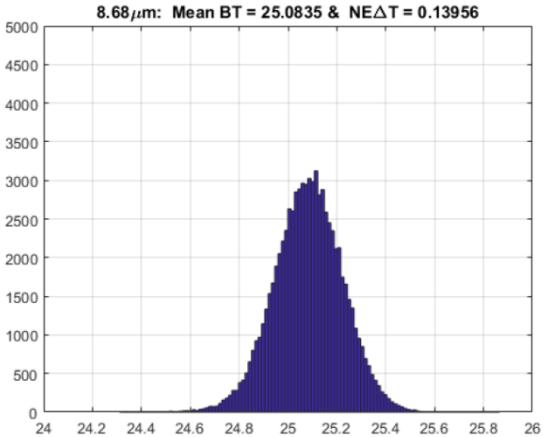
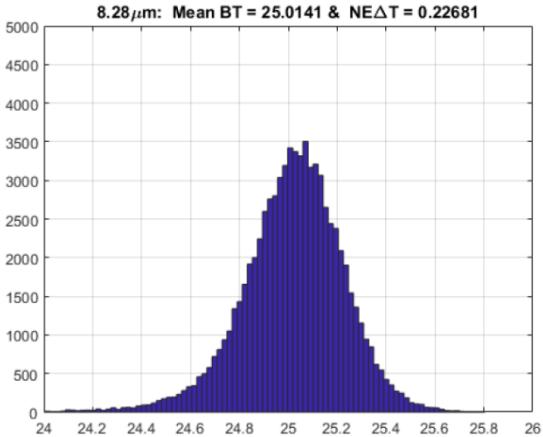
Dial In (C) Stabilizes at =

05.000
15.000
25.000
35.000
45.000
55.000
65.000

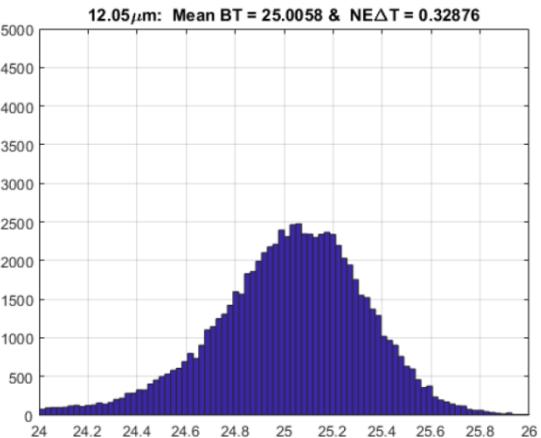
NIST Traceable Skin Temp (C):

05.72
15.20
24.95
34.64
44.50
54.43
64.21

Noise Equivalent Delta Temperature (NEΔT)

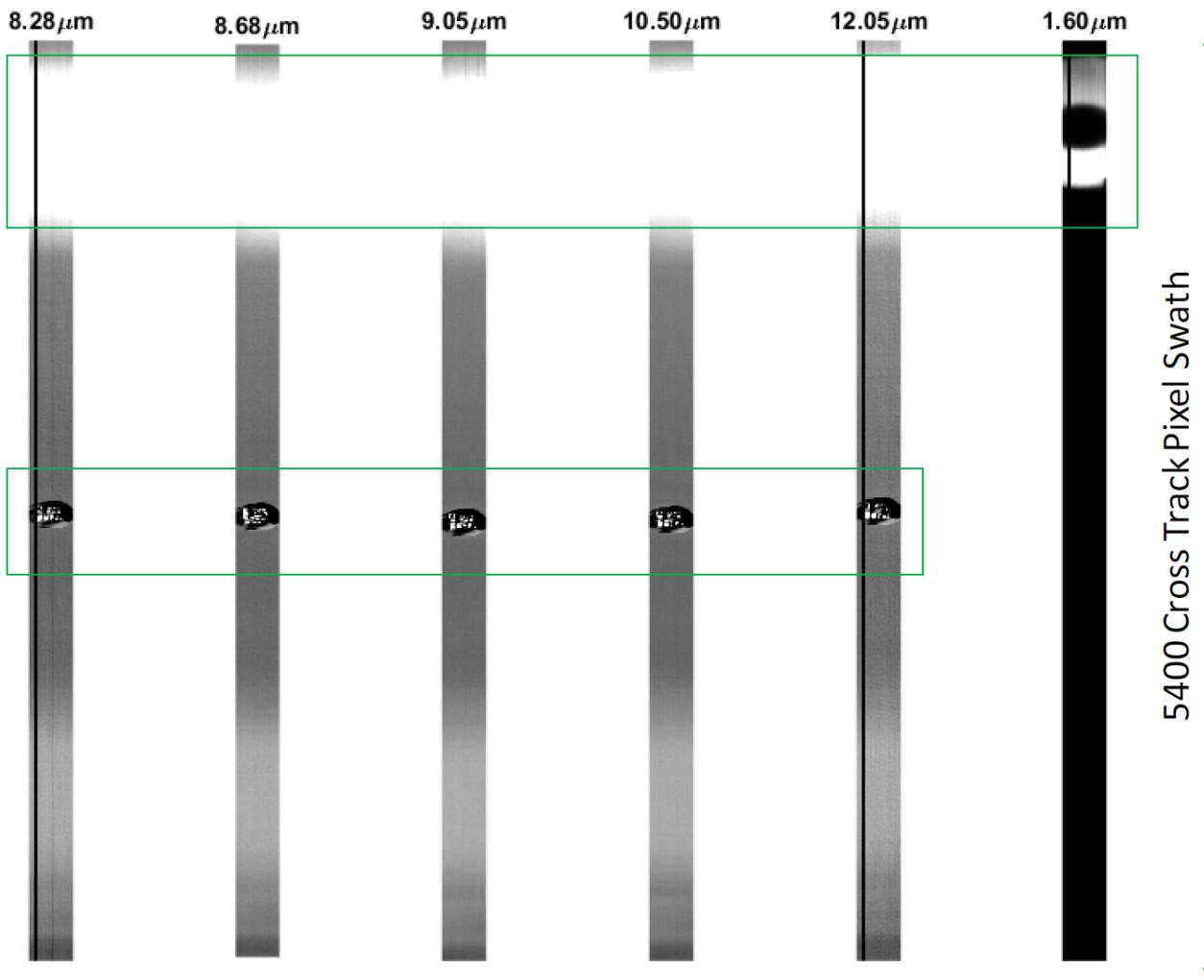


25C Scene NE Δ T and
BT histograms





Cross Track Scanning



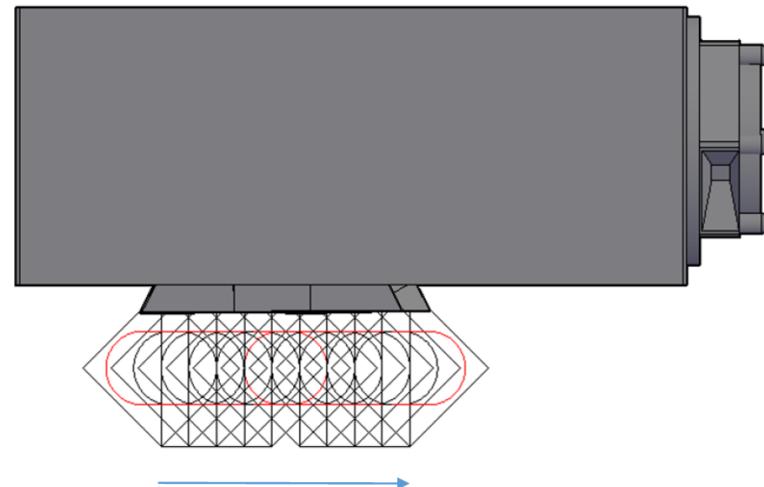
Angular Measurement

Radiance Vs. Angle & Field of Regard Stray light Test

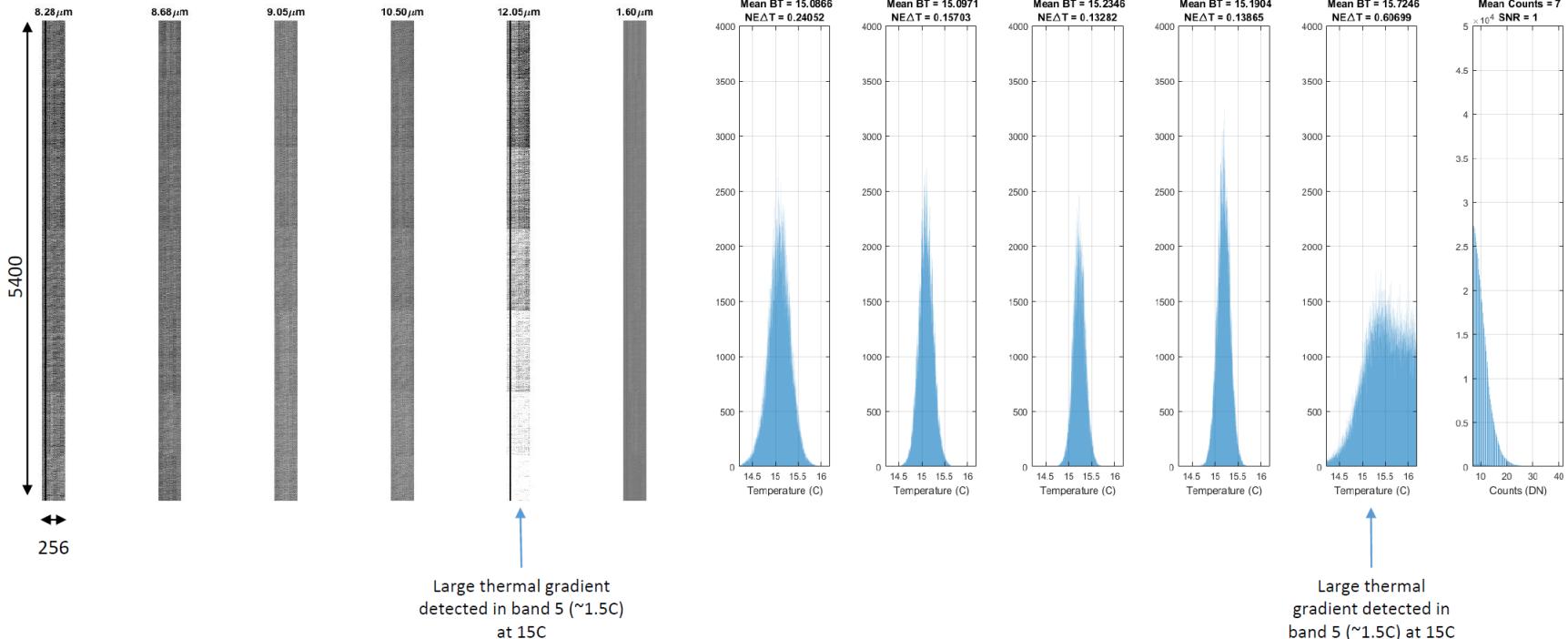
Acquire 5400x256 pixels with scene validation BB set to 15C



- 12x12 Blackbody held at 15C
- Spatially shifted over during subsequent frames (total time duration from first to last frame ~30min)
- 24hrs after cooling

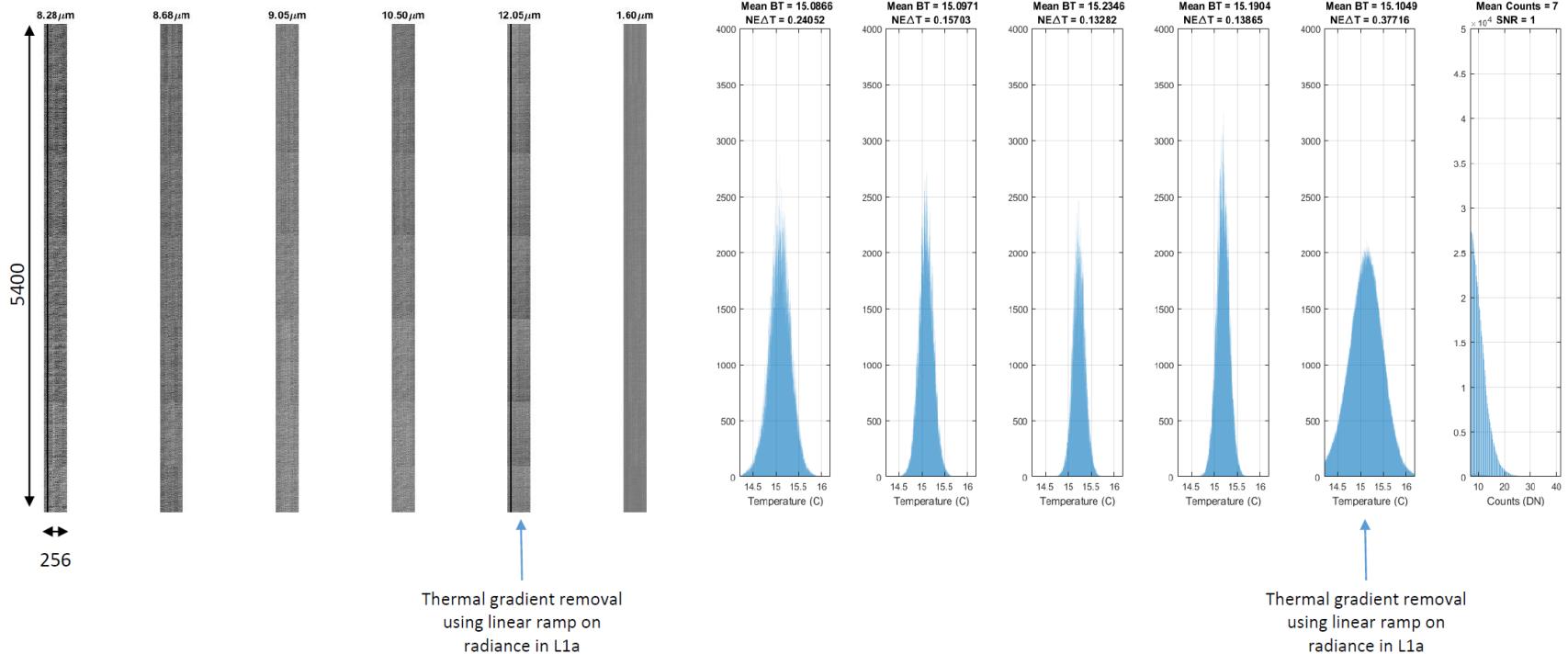


Radiance vs. Angle



Radiance vs. Angle

Field of Regard Stray light Test
 Acquire 5400x256 pixels with scene
 validation BB set to 15C



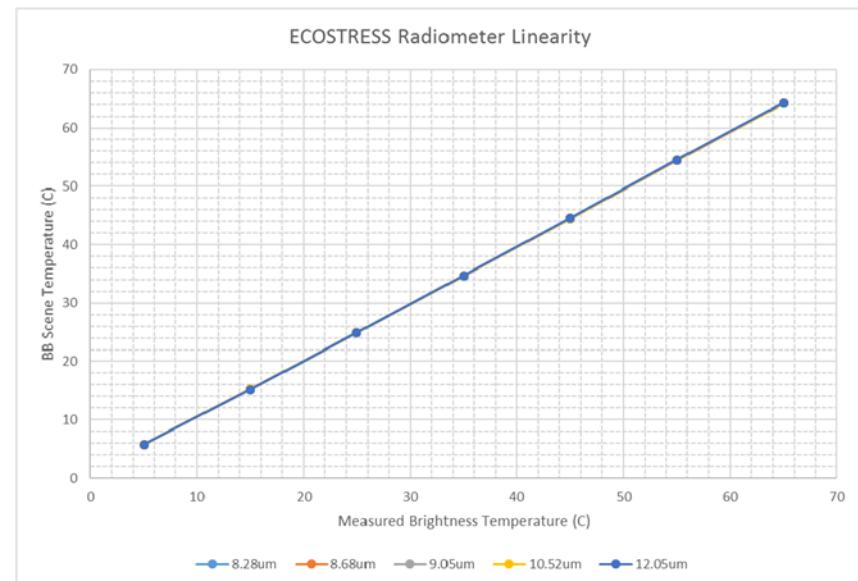
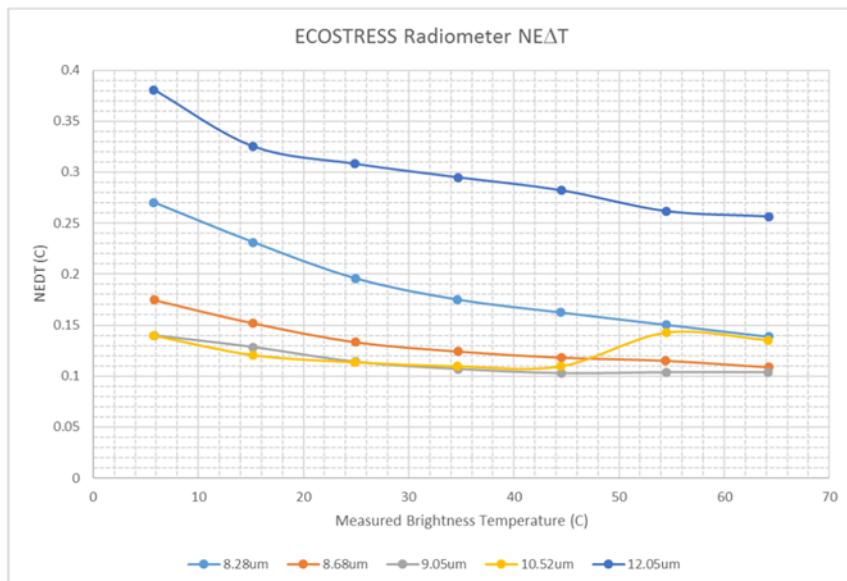


Radiometric Performance

02/14/2018

Apparent Brightness Temperature (C) in Air							
λ	5	15	25	35	45	55	65
8.28	5.7549	15.2154	24.9162	34.6474	44.4586	54.4844	64.2148
8.68	5.8143	15.2239	24.9315	34.7117	44.5094	54.4375	64.2088
9.05	5.7849	15.1912	24.9091	34.695	44.4895	54.4657	64.1959
10.52	5.768	15.2315	24.9074	34.6472	44.4405	54.47	64.1738
12.05	5.7653	15.1723	24.8835	34.6761	44.5168	54.4993	64.2388

NEΔT (C)								
λ	8.28	0.27022	0.23127	0.19591	0.17502	0.16239	0.15028	0.13855
8.68	0.1746	0.15183	0.1333	0.12412	0.11811	0.11505	0.10868	
9.05	0.13989	0.12851	0.114	0.10685	0.10283	0.10365	0.10376	
10.52	0.13988	0.12053	0.1134	0.10946	0.10942	0.14289	0.13544	
12.05	0.38065	0.32529	0.30804	0.29482	0.28213	0.2617	0.25642	



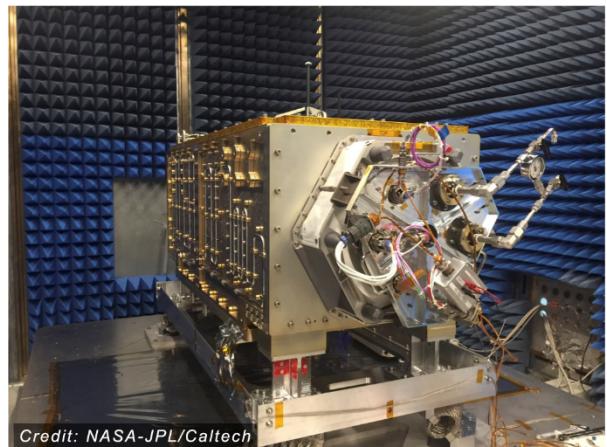
Payload Testing



Payload in TVAC



Payload on the shaker



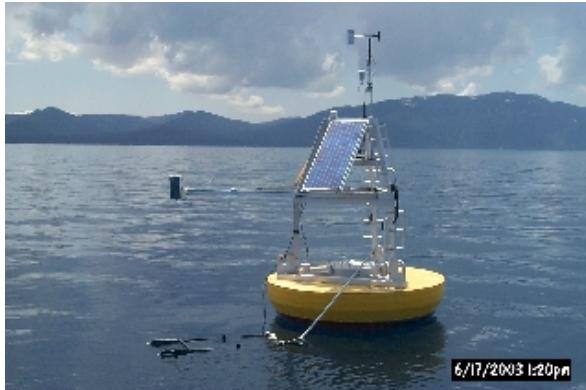
Payload in EMI/EMC



In-Orbit Checkout Measurement Validation

- Temperature validation from large lakes using skin temperature measurements measured in close proximity to the water surface.

Lake Tahoe

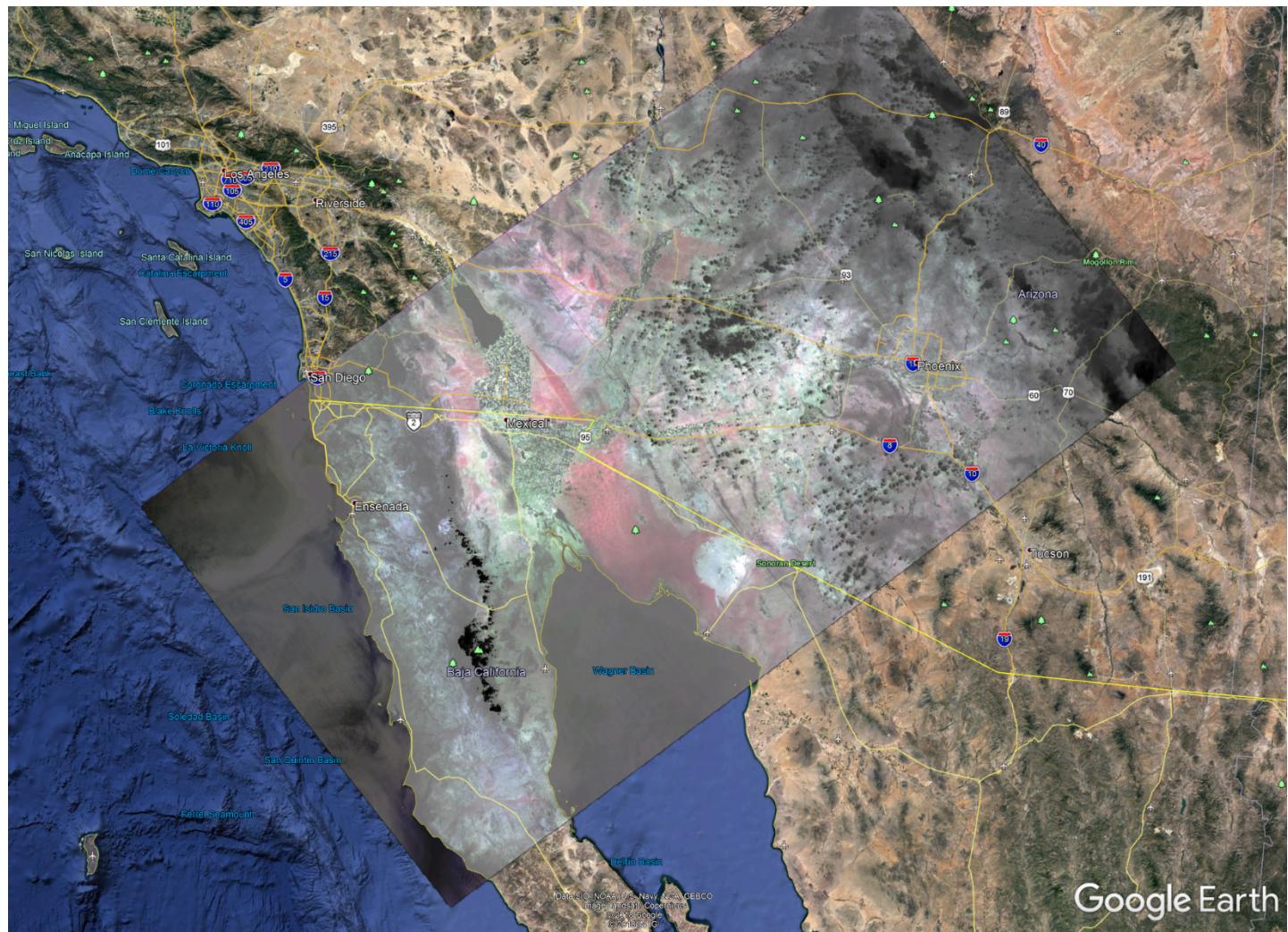


Salton Sea



Use L1B radiance at sensor combined with in-situ skin temperature measurements.

In-Orbit Checkout Measurement Validation



Overlay of ECOSTRESS thermal bands on google Earth (RGB representation of TIR bands $8.68\mu\text{m}$, $9.05\mu\text{m}$, $10.5\mu\text{m}$)



In-Orbit Checkout: Stability

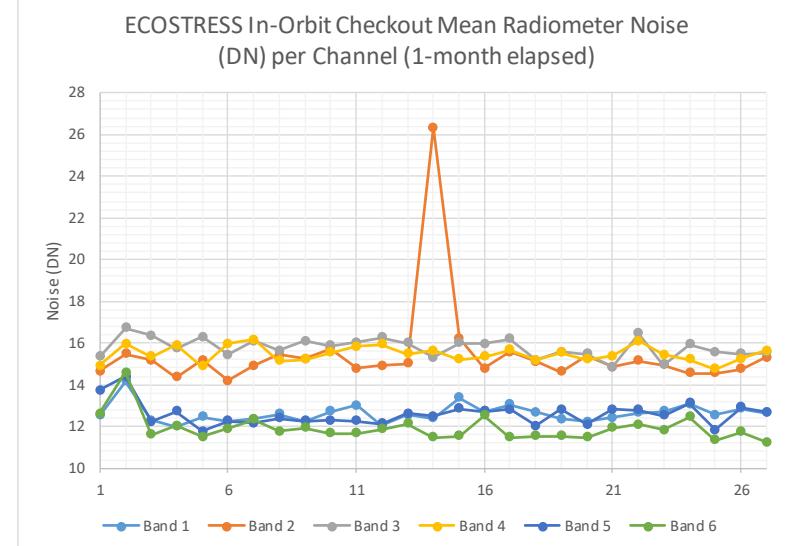


- Radiometer Noise

Excellent Stability: ~0.5DN over the first month of operation

ECOSTRESS In-Orbit Checkout Mean Detector Noise (DN) per Channel						
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6
Pre-ship	12.5241	14.6526	15.3226	14.903	13.7365	12.6
9-Jul	14.1597	15.4554	16.7092	15.9495	14.4004	14.5806
10-Jul	12.2895	15.1582	16.3401	15.3466	12.2048	11.5885
14-Jul	12.0029	14.3631	15.724	15.8984	12.7184	12.0252
15-Jul	12.4419	15.1864	16.2758	14.8947	11.752	11.4979
16-Jul	12.2065	14.1875	15.4214	15.9537	12.2615	11.8974
17-Jul	12.3503	14.8967	16.0845	16.15	12.1472	12.3261
18-Jul	12.5699	15.4451	15.63	15.1522	12.3843	11.7575
19-Jul	12.224	15.2423	16.0774	15.2217	12.2392	11.9397
21-Jul	12.7265	15.7364	15.8727	15.5312	12.2961	11.677
22-Jul	13.0104	14.7935	16.0102	15.8381	12.256	11.6477
23-Jul	12.0351	14.9114	16.2439	15.926	12.1336	11.8518
25-Jul	12.5582	15.0164	15.9832	15.4552	12.6123	12.1223
26-Jul	12.3845	26.3147	15.3013	15.6264	12.4874	11.4821
28-Jul	13.3617	16.2263	16.0059	15.2087	12.8431	11.5258
29-Jul	12.7066	14.7646	15.9601	15.3304	12.7275	12.5252
30-Jul	13.031	15.5754	16.1824	15.6648	12.8123	11.4807
31-Jul	12.6698	15.0952	15.1798	15.1603	12.0113	11.535
1-Aug	12.3663	14.611	15.5744	15.5209	12.7987	11.5421
2-Aug	12.2353	15.3873	15.4626	15.2176	12.096	11.4674
3-Aug	12.4067	14.8493	14.8493	15.3842	12.8128	11.9177
4-Aug	12.6329	15.1528	16.4511	16.1037	12.7688	12.0744
5-Aug	12.7122	14.9392	14.9392	15.4222	12.5062	11.8144
6-Aug	13.058	14.5555	15.9314	15.221	13.0991	12.4422
7-Aug	12.5517	14.558	15.5645	14.7362	11.8293	11.3257
8-Aug	12.8408	14.7322	15.4686	15.2334	12.8947	11.7134
9-Aug	12.6618	15.2892	15.533	15.645	12.6922	11.2245
STDDEV	0.45	0.45	0.46	0.37	0.52	0.64

Anomaly





In-Orbit Checkout: Stability

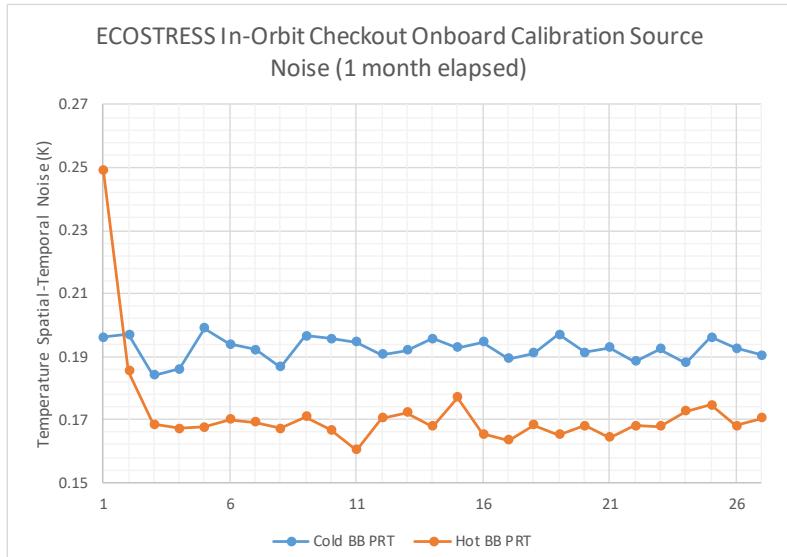


- Onboard Calibrator Temperature Noise (Substrate)

Excellent Stability: <50mk error, below the PRT specification

Cold BB <1K of variation over 1 month, Hot BB < 0.1K of variation over 1 month

ECOSTRESS In-Orbit Checkout Hot/Cold BB PRTs (K)				
	Cold BB Temp	Hot BB Temp	Cold Std	Hot Std
Pre-ship	293.7044	318.9403	0.1961	0.249
9-Jul	291.7438	318.9201	0.197	0.1853
10-Jul	291.4677	318.9431	0.1841	0.1685
14-Jul	291.8413	318.9993	0.1861	0.1672
15-Jul	291.4704	318.9743	0.199	0.1676
16-Jul	291.6982	318.9755	0.1939	0.1701
17-Jul	291.7055	319.0035	0.1921	0.1691
18-Jul	291.6274	318.977	0.1866	0.1671
19-Jul	291.7704	318.9897	0.1965	0.1708
21-Jul	291.5916	319.0143	0.1958	0.1667
22-Jul	291.5011	318.9972	0.1947	0.1604
23-Jul	291.7253	318.9909	0.1906	0.1705
25-Jul	291.8088	319.0032	0.1919	0.1723
26-Jul	291.6787	318.9775	0.1957	0.1679
28-Jul	291.7524	318.9714	0.1928	0.177
29-Jul	291.7093	318.9759	0.1947	0.1655
30-Jul	291.825	318.9771	0.1893	0.1634
31-Jul	291.9749	318.9821	0.1911	0.1682
1-Aug	292.056	319.0009	0.1971	0.1652
2-Aug	291.9664	318.9936	0.1913	0.1681
3-Aug	291.9238	319.0063	0.1928	0.1643
4-Aug	292.2035	318.977	0.1885	0.1681
5-Aug	292.1695	318.9807	0.1923	0.1679
6-Aug	292.0949	318.9698	0.1879	0.1726
7-Aug	291.8384	318.9859	0.1962	0.1746
8-Aug	291.954	318.9797	0.1927	0.168
9-Aug	291.9997	318.9648	0.1905	0.1704
ΔTEMP	0.7358	0.0942		





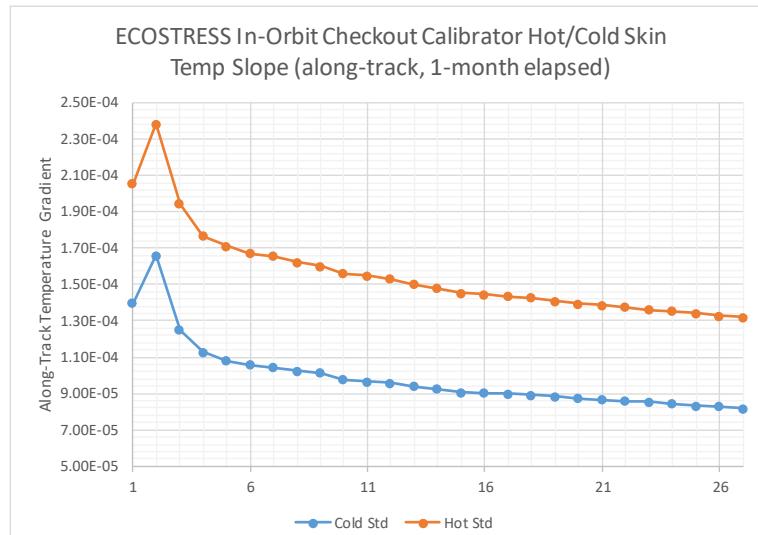
In-Orbit Checkout: Stability



- Onboard Calibrator Settling Time

Gradient not significant – not detected in temperature validation

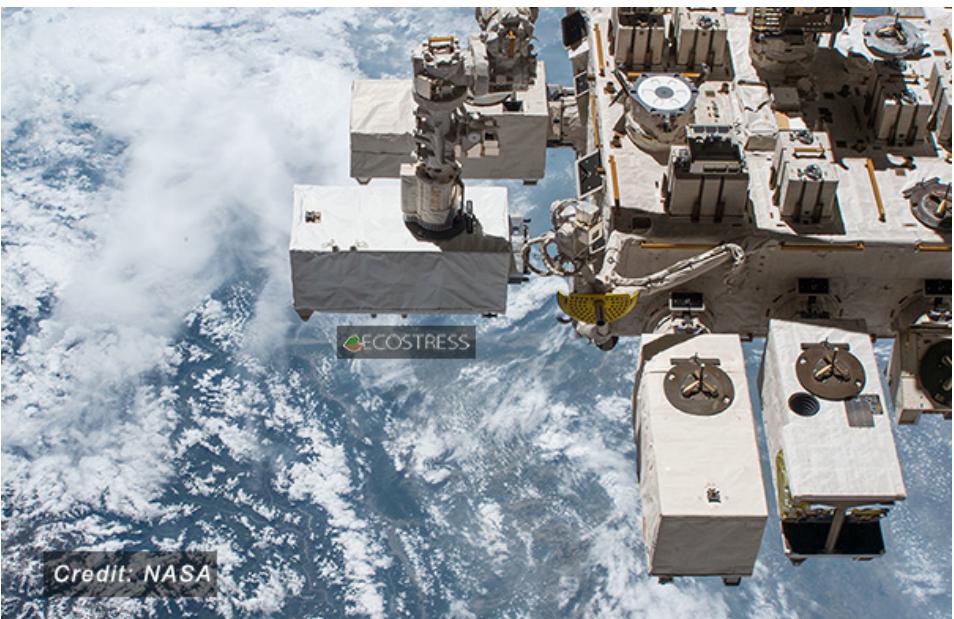
ECOSTRESS In-Orbit Checkout Calibrator Hot/Cold Skin Temp Slope (along-track)		
	Cold Std	Hot Std
Pre-ship	1.40E-04	2.05E-04
9-Jul	1.66E-04	2.38E-04
10-Jul	1.25E-04	1.94E-04
14-Jul	1.13E-04	1.77E-04
15-Jul	1.08E-04	1.71E-04
16-Jul	1.06E-04	1.67E-04
17-Jul	1.04E-04	1.66E-04
18-Jul	1.03E-04	1.62E-04
19-Jul	1.01E-04	1.60E-04
21-Jul	9.76E-05	1.56E-04
22-Jul	9.67E-05	1.55E-04
23-Jul	9.60E-05	1.53E-04
25-Jul	9.40E-05	1.50E-04
26-Jul	9.25E-05	1.48E-04
28-Jul	9.06E-05	1.45E-04
29-Jul	9.04E-05	1.45E-04
30-Jul	9.01E-05	1.44E-04
31-Jul	8.93E-05	1.43E-04
1-Aug	8.82E-05	1.41E-04
2-Aug	8.74E-05	1.39E-04
3-Aug	8.64E-05	1.39E-04
4-Aug	8.59E-05	1.37E-04
5-Aug	8.54E-05	1.36E-04
6-Aug	8.43E-05	1.35E-04
7-Aug	8.34E-05	1.34E-04
8-Aug	8.27E-05	1.33E-04
9-Aug	8.18E-05	1.32E-04



ECOSTRESS Summary

- ECOSTRESS passed all pre-flight reviews and was launched to the ISS 6:52 a.m. PDT (9:52 a.m. EDT) on Monday, July 2
- ECOSTRESS passed in-orbit checkout and is currently operating in phase E, science ops
- Visit ecostress.jpl.nasa.gov for more info

NASA's new Earth-observing experiment, ECOSTRESS, is installed on the International Space Station. ECOSTRESS will provide thermal infrared measurements of Earth's surface allowing scientists to assess plant water use and response to changes in water availability. Credit: NASA



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